Current-voltage characteristics

In this experiment you will use a computerised source and measure unit to obtain the current-voltage characteristics of a variety of interesting components, and attempt to explain what you observe.

The data acquisition software and hardware

The IVSMU software (in the SCIENCE menu) uses the USB1208FS data acquisition module as a Source and Measure Unit. It is the equivalent of both a waveform generator which drives a current through the device under test, and two meters which measure current (I) and voltage (V).

The source waveform

Connect the channel 0 output of the DAC[1] buffer amplifier to an oscilloscope. When Run is clicked, the scope should show a voltage that slowly rises and falls. Adjust the source control to give 100 points, a time step of 10 ms and a maximum voltage of 10 V.

Observe that the waveform produced is not completely smooth, but has steps. Verify that the steps are consistent with the settings of the source control, and find out how its settings affect the waveform. Record your observations. It is useful to know that "N points" refers to the number of points per full cycle.

Current - Voltage characteristic of a resistor

It is always a good move to start by measuring something you understand. Connect the circuit shown in figure 1, in which channel 0 of the SMU is used to measure the voltage across a 1kΩ resistor (and hence the current in mA), and channel 1 measures the voltage across the component under test, in this case a 100 Ω resistor. The DAC supplies the current, which of course will be the same in both components.

Adjust the SMU settings to produce a good characteristic, print it out, and check that the resistor obeys Ohm's law.

[1] DAC = Digital to analogue converter

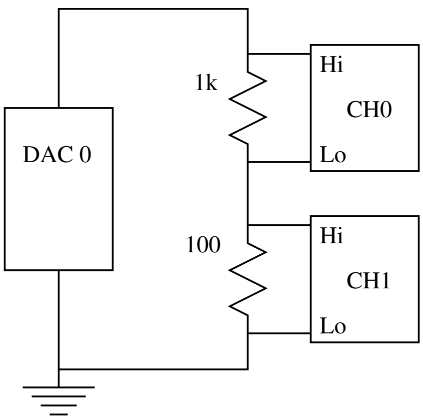

Figure 1: Connection to measure a 100 Ω resistor

Light emitting diodes

Replace the 100 Ω resistor by a light emitting diode (LED). The conventional way to connect it is with the cathode (the larger internal electrode) to ground. Adjust the settings to produce a curve that shows the sudden conduction that occurs when the anode is sufficiently positive, as well as the blocking of reverse current. Where in the plot is light emitted?

The "forward voltage" of a diode is defined as the voltage that develops when it is passing a standard current, for example 1 mA. What is the forward voltage for your diode? Why does it not matter a great deal what value of standard current is used? **Q**
Repeat your measurements with one or more LEDs of different colours.

LEDs are always used with a series resistor (like the 1 kΩ in this case) to determine the current. Why is it not practical to light up an LED using a voltage source and no resistor? **Q**

Diode leakage

An ideal diode would pass no current when the cathode is positive. In fact, small currents do flow, but you will need to reduce the current taken from the circuit by the SMU voltage inputs in order to have a chance of seeing it. First add the high impedance buffer amplifiers between the measuring channels and the test circuit, as shown in figure2. With an LED in the circuit, you should see the same characteristic as before, because the added amplifiers do not alter the voltages; they simply prevent the measuring channels from stealing current from the circuit.

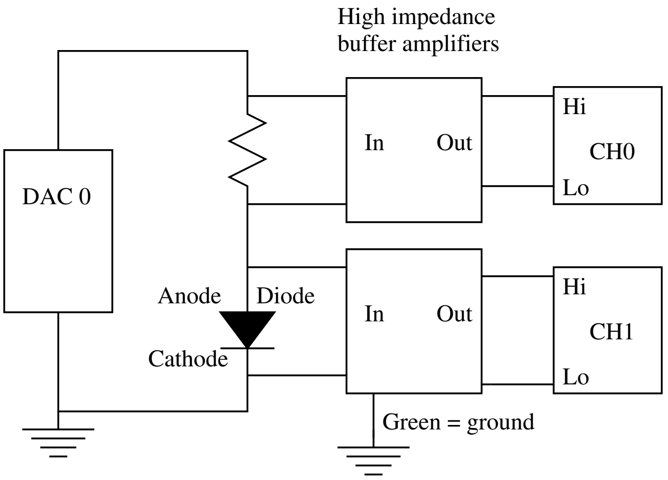

Figure 2: Measuring diode leakage current

Increase the resistor to 1 MΩ to get better current sensitivity. With the LED, you probably still won't see much (if any) current, but you should be able to put a pretty low *limit* on the LED leakage current from your measurements.

Replace the LED by a germanium diode. In this case you should be able to measure the reverse leakage current. How and why does it vary with temperature? Find out by warming it with your fingers or cooling it with freezer spray.

Shockley gave a simple theoretical expression for the current-voltage curve of an idealised diode:

$$I = I_s(\exp[V/V_T] - 1)\,,$$

where I_s depends on the diode and temperature, but is independent of voltage, and $V_T = k_B T/e$ in the ideal case. How close does your real germanium diode come to this?

Capacitor

Go back to a 1 kΩ series resistor (with or without the high impedance buffers), and replace the diode by a 1 μF capacitor. Sweeping as fast as possible, you should see two distinct values of current. Why is this? Think about the sweep waveform, and recall the expression for the current in a capacitor, $I = CdV/dT$. **Q**

Light bulb

The current-voltage characteristic of a light bulb is very odd. Use resistors in the range 10-100 Ω, and no high-impedance preamplifier. Plot and try to explain your results. They will depend on the magnitude and the speed of the sweep. Be as quantitative as possible.

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